

A Three-dimensional Analysis Method for Edentulous Mandibular Ridge Shape

Mamoru MURAKAMI¹, Naotsugu KAWAHATA² and Eiichi NAGAOKA¹

¹Department of Oral and Maxillofacial Prosthodontics, Field of Oral and Maxillofacial Rehabilitation, Course for Advanced Therapeutics, Kagoshima University Graduate School of Medical and Dental Sciences 8-35-1, Sakuragaoka, Kagoshima, 890-8544, Japan

²Dentist in private practice, 361-2, Kawaharajyou, Tenri, 632-0016, Japan

Corresponding author, Mamoru MURAKAMI; E-mail: kaku@dentb.hal.kagoshima-u.ac.jp

Received June 29, 2006 / Accepted January 31, 2007

The aim of this study was to develop a three-dimensional method to analyze edentulous ridge shapes.

A laser projection method was used to record the shape of edentulous plaster models. Contour of residual ridge on the reconstructed image was then subdivided into small triangles, and a 'normal line' representing the center of gravity of each triangle was determined buccolingually and anteroposteriorly. Angle between the normal line on the residual ridge and the tentative occlusal plane was calculated for each triangle. These angles were then used to analyze the ridge shape.

This method was used to analyze the ridges of 20 edentulous patients with excessive bone resorption. The results suggested that this method was useful for analyzing edentulous ridges regardless of ridge shape and degree of resorption.

Keywords: Edentulous ridge, Laser measurement, Complete denture

INTRODUCTION

The buccolingual position of artificial posterior teeth is limited and determined by the shape of the posterior ridge — which is the stress-bearing area supporting occlusal forces. To achieve maximum stability in complete dentures, lever balance should also be considered as a pivotal factor¹⁾. On this note, the comparatively flat area (CFA) of ridge may be adequate to achieve lever balance in the stress-bearing area. While it is important to examine these ridge areas objectively and accurately, existing methods that examine residual ridge shape²⁻⁴⁾ have not been able to analyze this CFA. Against this background, we had previously designed a system to analyze the CFA — including ridge crest — on a reconstructed image of the ridge contour by using a non-contact shape measuring device and computer software^{5,6)}.

In the abovementioned analysis method, the software had a function to determine the CFA using tangent lines at the buccal and lingual sides of the ridge contour in the frontal section interpolated by a spline curve. Ridge crest was calculated as the highest point of the upward convexity of the ridge contour in the frontal section. However, this software was not adequate to analyze flat or concave ridges without a ridge crest.

Some textbooks on complete denture prosthodontics^{1,7,8,9)} state that mandibular residual ridges with severe bone resorption have a steep upward slope at the anterior area to the retromolar pad, and that positioning artificial posterior teeth in this area could cause the lower denture to move anteriorly⁷⁾. By the same token, a posteriorly inclined ridge could result in denture movement in a

posterior direction. Therefore, it is necessary to carefully examine these slope areas to provide optimal stabilization of complete dentures.

To allow analysis of all ridge shapes, an improved software was developed in another study¹⁰⁾ using a normal line instead of a tangent line. This software was used to examine the anteroposterior and buccolingual inclinations of the lower distal extension ridge¹⁰⁾. Results showed that this software could be used to analyze any ridge shape. However, analysis area was limited to the distal extension edentulous ridge.

In the present study, we further improved the software to allow analysis of the entire edentulous ridge. In terms of experimental strategy, this software was first used to analyze the residual ridge of an edentulous patient with average bone resorption. Then, it was used to analyze the ridges of 20 edentulous patients with a spectrum of ridge shapes resulting from severe bone resorption.

MATERIALS AND METHODS

Analysis system

The system consisted of a non-contact three-dimensional shape measuring device (Surflacer VMS-250R, UNISN Inc., Osaka, Japan), a personal computer for controlling the measuring device, a personal computer for analyzing data, and a custom-developed software for shape analysis using Visual Basic Ver.6.0 (Microsoft Co. Ltd., USA). The software, which was an improved version of the existing software for analyzing distal extension edentulous ridge, was designed to analyze the entire edentulous ridge using the tentative plane of occlusion of a wax denture and the normal line on the

edentulous ridge. The software also allowed the operator to examine the position of the artificial posterior teeth on the stress-bearing area in the edentulous ridge.

1. Measurement method

Figure 1 shows the upper and lower plaster models and wax dentures mounted on the fixed apparatus, which was attached to the chuck of the rotational table of the measuring device. The two-object assemblies were positioned by leveling the tentative occlusal plane of the wax denture, and where the anteroposterior and lateral directions of the plaster model were set as X- and Y-axes, respectively. In the present study, the lower plaster model and wax denture were examined. The measuring device took

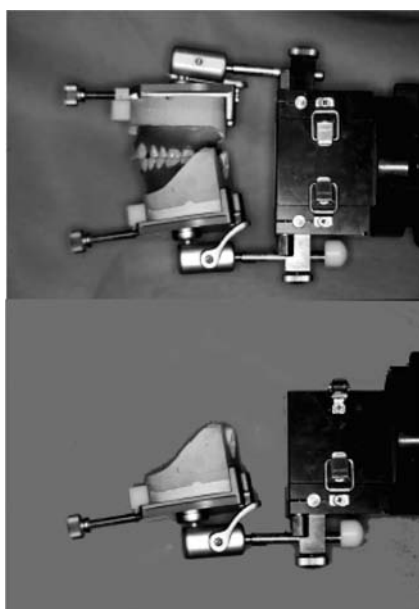


Fig. 1 Plaster models and wax dentures mounted on the fixed apparatus.

measurements at intervals of 0.25 mm in both directions.

2. Analysis method

To generate a program using a normal line, we regarded the ridge shape as being composed of quadrangles with intervals of 0.25 mm in the directions of X and Y-axes. Each quadrangle was then divided into two small triangles with a diagonal line. The center of gravity of the respective triangles was used to set up the normal line (Fig. 2). Areas suitable for supporting occlusal forces were defined as CFA with an angle of $90 \pm 5^\circ$ between the normal line and the tentative plane of occlusion. This angle was defined as the normal line angle (Fig. 3).

Each normal line was projected to the two planes (X-Z plane and Y-Z plane) on the measurement

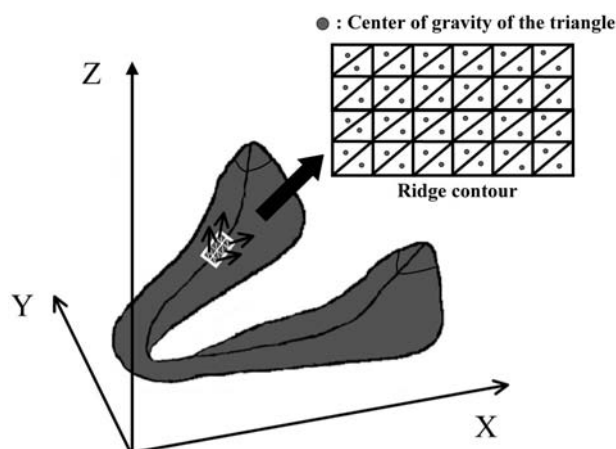


Fig. 2 Schema of ridge contour and small triangles.

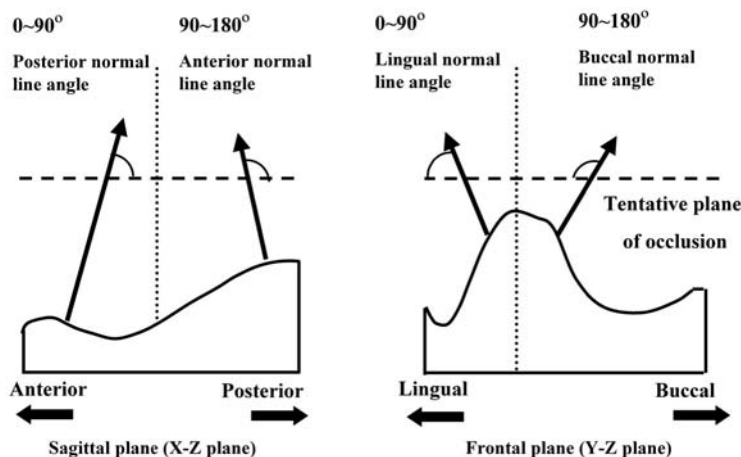


Fig. 3 Determination of stress-bearing area with an angle of inclination between $90 \pm 5^\circ$ and $90 \pm 30^\circ$.

coordinates. The X-Z plane and Y-Z plane corresponded to the sagittal and frontal sections, respectively. We calculated two normal line angles ($90 + \quad^\circ$, $90 - \quad^\circ$) on the respective planes in the anteroposterior and buccolingual directions (Fig. 3). Six levels of CFA between $90 \pm 5^\circ$ and $90 \pm 30^\circ$ were classified at intervals of five degrees from the normal line angle in both anteroposterior and buccolingual directions. In this study, ridges of $90 \pm 5^\circ$; $90 \pm 10^\circ$; $90 \pm 15^\circ$; $90 \pm 20^\circ$; $90 \pm 25^\circ$; and $90 \pm 30^\circ$ were called A-ridge, B-ridge, C-ridge, D-ridge, E-ridge, and F-ridge, respectively.

Analysis of a mandibular residual ridge with average bone resorption of an edentulous patient

Using the plaster model with average bone resorption (Fig. 1), the CFA from A-ridge to F-ridge were examined and images of the artificial tooth arch were superimposed on the ridge. In each residual ridge, the CFA was displayed as a white area and other part as a dark area.

Analysis of varied shapes of mandibular residual ridges resulting from severe bone resorption in 20 edentulous patients

Varied ridge forms resulting from severe bone resorption in 20 edentulous patients (7 males and 13 females) were examined and divided into three categories: tapered ridge, flat ridge, and lingually sloping

ridge. Tapered ridge was the narrow CFA with residual ridge crest. Flat ridge was buccolingually broad CFA without residual ridge crest. With both tapered ridge and flat ridge, the horizontal CFA analyzed using $90 \pm 10^\circ$ was displayed as a white area. As for the lingually sloping ridge which did not have the horizontal CFA, it was displayed as a white area (normal line angle between 0 and 90 degrees) on the left side and the reverse as a dark area (normal line angle between 90 and 180 degrees) on the right side.

RESULTS

Analysis results of mandibular residual ridge with average bone resorption

Figure 4 shows the analysis results for A-ridge to F-ridge with the artificial tooth arch superimposed on the A-ridge. This figure shows the entire area of the edentulous ridge. In each residual ridge, the CFA was displayed as a white area and other part as a dark area. White areas indicated by arrows were analyzed as CFA including the ridge crest. This area spread gradually as the normal line angle increased. In the A-ridge, the functional cusps of posterior teeth were located on the CFA.

Analysis results of varied shapes of mandibular residual ridges with severe alveolar bone resorption

Table 1 shows the analysis result for the varied

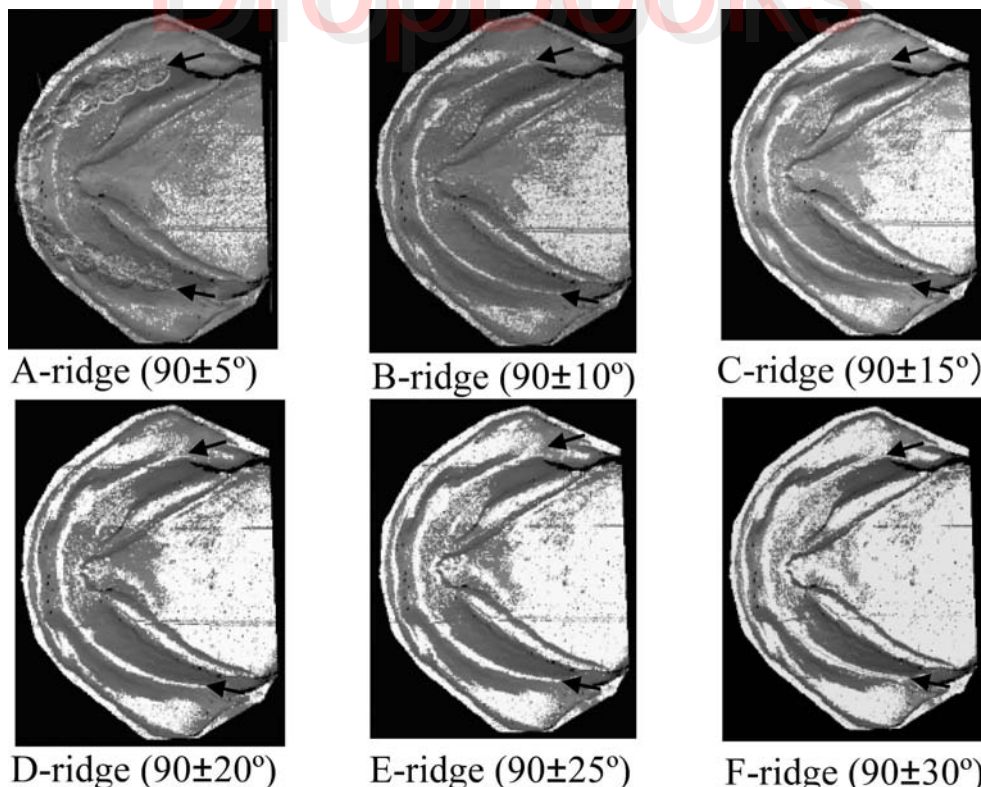


Fig. 4 Analysis results for an average ridge from A-ridge to F-ridge. Superimposition of the analysis results for an edentulous ridge and artificial teeth.

Table 1 Analysis results for varied shapes of mandibular residual ridges resulting from severe bone resorption in 20 edentulous patients

20 edentulous patients with severe bone resorption			Rate of respective ridge shape		
Subject	Number	Age (Average)	Tapered ridge	Flat ridge	Lingually sloping ridge
			Number (%)	Number (%)	Number (%)
Male	7	64 - 81(74.4)	2(10)	3(15)	2(10)
Female	13	56 - 84(69.5)	4(20)	5(25)	4(20)

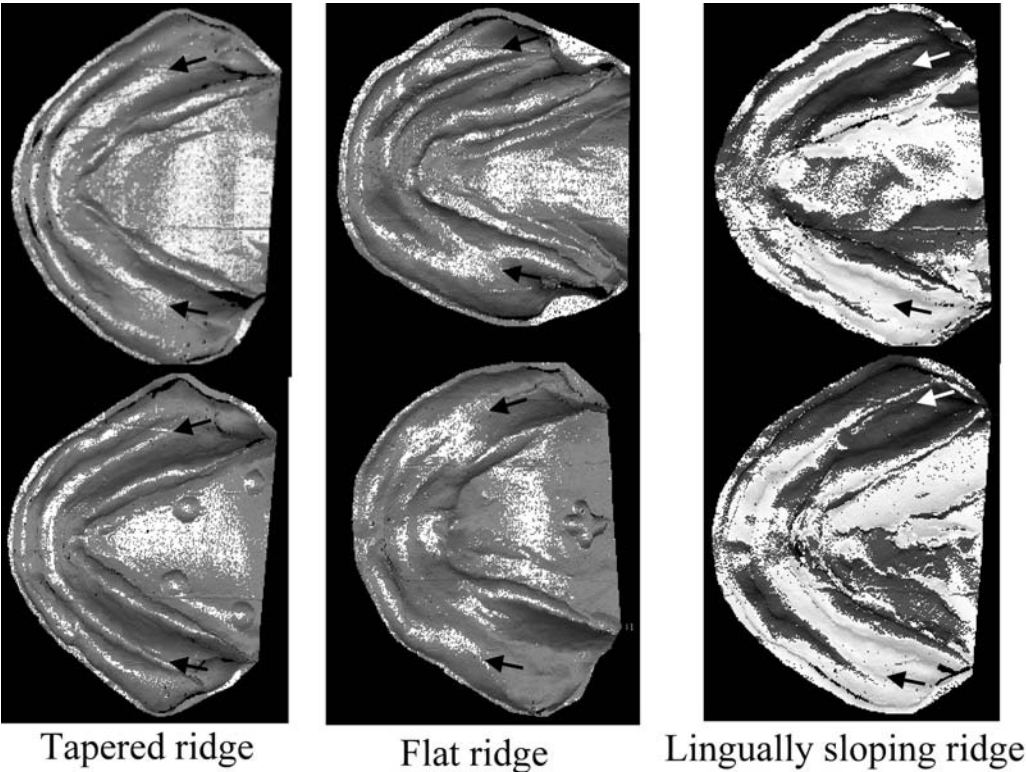


Fig. 5 Analysis results for tapered ridge, flat ridge, and lingually sloping ridge with B-ridge.

shapes of mandibular residual ridges resulting from severe bone resorption in 20 edentulous patients. Rates of tapered ridge, flat ridge, and lingually sloping ridge were 30%, 40%, and 30%, respectively.

Figure 5 shows two examples of analysis results for the tapered ridge, flat ridge, and lingually sloping ridge. White and dark areas in the tapered and flat ridges, as those shown in Fig. 4, are displayed. In addition, the white areas indicated by arrows in the tapered and flat ridges show the horizontal CFA analyzed using $90 \pm 10^\circ$; i.e., the B-ridge shown in Fig. 4. CFA in the tapered ridge was narrower than that of the flat ridge.

In the lingually sloping ridge, white area indicated by the arrow on the left side shows the area

where the normal line angles were less than 90° . On the right side, the lingually sloping ridge can be seen as the dark area shown by the white arrow.

DISCUSSION

Significance of analyzing ridge shape

In cases where an interalveolar crest line angle is less than 80° in the first molar region, Gysi advocated the interalveolar crest line rule which recommends the cross-bite arrangement to be adopted⁽¹⁾. The line connecting the upper and lower ridge crests indicate that a complete denture with the posterior tooth arch arranged buccal to the ridge crest will be easily tipped out of position. On this note, in a study by

Sanghvi *et al.*, it was reported that 69 out of 150 edentulous patients (46%) had an interalveolar crest line angle of less than 80°; thereby requiring a cross-bite arrangement¹²⁾.

In another study about the influence of buccolingual position of artificial teeth, Kawano *et al.* compared the pressure exerted on supporting tissue under the lower complete denture. In this study¹³⁾, the posterior tooth arch was arranged in three different positions in a buccolingual direction: according to interalveolar crest line rule (C-position), 3 mm buccal of the C-position, and 3 mm lingual of the C-position. Significant increases in pressure were observed when the posterior tooth arch was positioned buccally and lingually of the C-position. Conversely, least pressure was exerted when the posterior teeth were arranged in the C-position.

Similarly, using a two-dimensional finite element method, Nishigawa *et al.* reported that the stress value at the buccal border of the maxillary model increased as the loading point moved to the buccal side¹⁴⁾. Moreover, stress value for the loading point on the furthest buccal point was twice as large as that on the ridge crest.

Taken together, results of Kawano *et al.*¹³⁾ and Nishigawa *et al.*¹⁴⁾ indicated that dentures with the posterior tooth arch arranged to the buccal side of the interalveolar crest line resulted in increased pressure, which could then cause bone resorption.

In terms of the influence of buccolingual position on chewing efficiency, Kapur *et al.* conducted a study with 12 complete denture wearers with the posterior teeth arranged in different buccolingual positions¹⁵⁾. Results showed that when the posterior teeth were positioned buccally further from the ridge crest, the lower would be the chewing efficiency¹⁵⁾.

Indeed, these studies¹³⁻¹⁵⁾ evidently showed that before determining the position of the posterior teeth, it is important to use an appropriate analysis method to examine the ridge shape including the ridge crest.

In our previous report in which we used tangent lines, ridge crest lines and the consecutive interalveolar crest lines of ridge with an average ridge form were superimposed on the surface of an edentulous cast⁶⁾. This was done to determine the appropriate buccolingual position of the posterior teeth. In the present study, superimposition of the artificial tooth arch on the A-ridge (Fig. 4) seemed to visualize the buccolingual position of the posterior artificial teeth on the CFA, including the ridge crest. However, in cases with no apparent ridge crest as a result of severe alveolar bone resorption, it is more important to consider the positional relationship between the upper and lower ridges, as shown in Fig. 5.

Analysis method

1. Measurement accuracy

Measurement interval affects the accuracy of the reconstructed images of the objects¹⁶⁾. In the present study, measurement interval was 0.25 mm in both anteroposterior and lateral directions. Wakabayashi *et al.*¹⁷⁾ reported that a measurement interval of 0.2 mm was small enough to reproduce the shape of the occlusal surface of a dentulous plaster model. In the present study, the object studied was a plaster model of an edentulous ridge with a less complicated shape than the occlusal surface. According to the manufacturer of the device we used¹⁸⁾, measurement accuracy was 0.05 mm in the height direction when the measurement interval was 0.25 mm. Based on the report of Wakabayashi *et al.*¹⁷⁾ and manufacturer's information¹⁸⁾, we therefore judged that this device would aptly serve our experimental purposes.

2. Measurement time

Measurement interval and size of measurement area affect the measurement time. In terms of measurement interval, it was 0.25 mm as reported by Wakabayashi *et al.*¹⁷⁾ and the same as was used in our previous studies^{5,6,10)}.

When a slit light is used for measurement, measurement time is shorter as compared to a spotlight. The measurement device we used was equipped with a slit light, which took about 20 minutes to measure both the edentulous model and lower wax denture.

Using a light-stripe method to emit a horizontal-stripe laser and to scan the object using a galvanic mirror, Sohmura *et al.*¹⁶⁾ was able to measure a dentulous plaster model in about 0.6 seconds with a measurement interval of 0.4 mm. In other words, measurement time could be even shorter if a light-stripe method were used than the measurement system used in the current study.

3. Analysis software

In our previous study, the software used was capable of analyzing the CFA using tangent lines and thereby determined the most suitable position for the artificial posterior teeth for complete dentures⁵⁾. This software determined the CFA as the area between two points on the ridge contacting the tangent lines at the buccal and lingual sides in the frontal section interpolated by spline curves only in the lateral direction. The CFA changed by the magnitude of the angle between the tangent line and the tentative occlusal plane. In the previous study, we adopted 30° as the angle between the tangent line and the tentative occlusal plane. However, in flat, depressed, or lingually inclined ridges resulting from severe bone resorption in the edentulous mandible, it was impossible to find a point where the tangent line contacted the ridge contour in order to examine the stress-bearing area including the ridge crest.

To rectify method deficiency, we therefore designed a shape analysis system using the normal line angle and used it to examine the edentulous mandibular distal extension area¹⁰. Results showed that this system could be used for examining not only the CFA including ridge crest, but also ridges with no ridge crest sloping anteroposteriorly or buccolingually. However, this software was limited to analyzing the distal extension of the edentulous ridge. Accordingly then, in the present study, we improved the software to enable it to analyze the entire area of the edentulous ridge.

Analysis results

Based on the analysis results obtained for an edentulous ridge with an average ridge form, it was shown that the improvised software could analyze the CFA

including ridge crest over the entire area of the edentulous ridge as effectively as our previous system using tangent lines^{5,6}. The CFA, including the ridge crest, changed with the normal line angle as shown in Fig. 4, and corresponded to the posterior residual ridge crest zone reported by Takamata *et al.*¹⁹ using moiré topography apparatus. Takamata *et al.* reported that the posterior residual ridge crest zone changed according to the buccolingual width of the moiré striped pattern¹⁹. The third moiré fringe lines at the buccal and lingual sides furthest from ridge crest were selected as reference lines for the posterior residual ridge crest zone.

Takamata *et al.* also investigated the overlapping zones in the posterior residual ridge crest zones of maxillary and mandibular casts mounted on articulators¹⁹. The 20 pairs of overlapping zones were examined according to the area of overlap in an

anteroposterior direction. Full overlapping zones were found in 65% of the 20 pairs in the area from the first premolar to the second molar, 27.5% had partial overlapping zones, and 7.5% had no overlapping zones. Varied patterns in the overlapping zone were caused by the different rates of alveolar bone resorption between the maxillary and mandibular ridges. Generally, the width of the maxillary alveolar arch decreases, whereas the width of the mandibular alveolar arch increases^{7,8,14}. The overlapping zone with an apparent ridge crest in the report of Takamata *et al.* is useful as a reference for positioning the posterior artificial teeth. However, flat and lingually sloping ridges with no ridge crest need a reference other than the ridge crest to position the posterior teeth.

On the other hand, Beresin and Schiesser advocated positioning the artificial teeth in the neutral zone (NZ) to be in harmony with normal neuromuscular function²⁰. Fahmi radiographically examined the buccolingual relationship between the center of NZ and the mandibular ridge crest by adapting stainless steel wires in 21 edentulous patients²¹. The results were analyzed according to the period of edentulousness. The longer the period of edentulousness, the more was the center of NZ located to the buccal side of the mandibular ridge crest. Thus, residual alveolar ridge crest changes its location in a buccolingual direction due to the progress of alveolar bone resorption. Furthermore, severe bone resorption results in flat and lingually sloping ridges with no apparent ridge crest. Consequently, it is useful to use the concept of the center of NZ as a reference instead of the ridge crest.

As shown in Fig. 5, results were obtained for

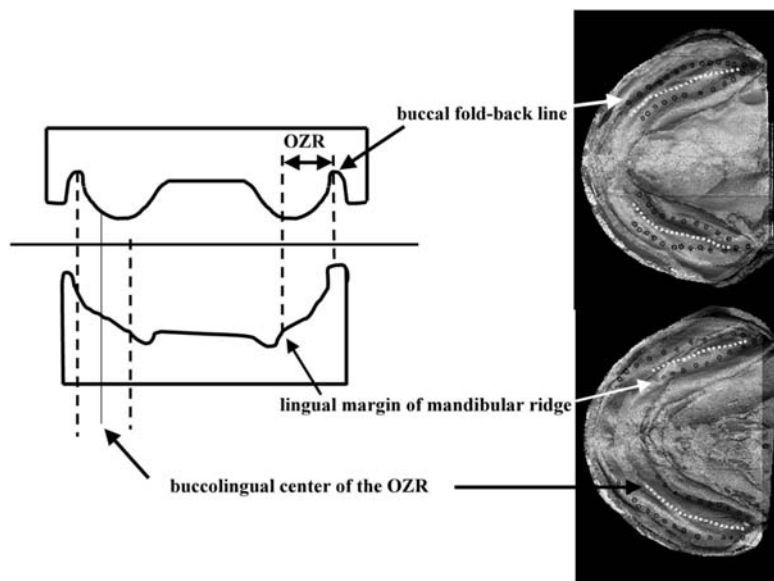


Fig. 6 Method of determining the OZR and analysis results for lingually sloping ridge.

differently shaped mandibular residual ridges with severe alveolar bone resorption. It was evident that the present analysis method using the normal line angle could analyze ridge shapes not only for tapered ridges, but also for flat and lingually sloping ridges with no ridge crest. It should be noted that for flat and lingually sloping ridges, the buccolingual position of posterior teeth could not be obtained by analyzing the CFA including ridge crest (as in our previous report⁶⁾) or by using posterior ridge crest zone (as by Takamata *et al.*¹⁹⁾). Against this background, it was necessary to use references such as the center of NZ when analyzing these ridges. However, determining the NZ requires the use of the flange technique.

To circumvent the use of flange technique, we examined these ridges with no apparent ridge crests using the overlapping zones of maxillary and mandibular ridges. This was a simpler method to determine the buccolingual position of posterior teeth than the flange technique. In this method, the margin on the buccal side of maxillary ridge was determined by the buccal fold-back line of the maxillary ridge, while the margin on the lingual side of mandibular ridge was determined by the mylohyoid ridge. These two margins then delineated the overlapping zone of ridge (OZR), which was used as a reference area for the buccolingual positioning of the posterior teeth instead of NZ.

Figure 6 shows the method for determining the OZR, and the analysis results for the lingually sloping ridge are shown in Fig. 5. Image of the maxillary ridge was superimposed on the lingually sloping ridge. In this figure, buccal fold-back line of the maxillary ridge and the lingual margin of the mandibular ridge are shown as small circles. Subsequently, the buccolingual center of OZR, which corresponded to the buccolingual center of NZ as reported by Fahmi²¹⁾, was examined. It is shown by white dotted lines in Fig. 6. In addition, in the lingually sloping mandibular ridge, OZR and the buccolingual center of OZR could be analyzed. This time, points applicable to the midpoint of buccolingual width of OZR were selected by the operator.

Based on the technique described and the results given in the present study, it was shown that the herein developed three-dimensional method could be used to analyze residual ridges of any shape.

CONCLUSIONS

We have developed a method to evaluate the entire area of fully edentulous ridges by referring to the normal line angle of the edentulous ridge. In terms of experimental approach, the average residual ridge of one edentulous patient was first analyzed, and

then ridges of varied shapes in 20 edentulous patients with severe ridge resorption.

Based on the results obtained in the present study, it was concluded that this system not only evaluated the CFA, but also varied ridge shapes to determine the most suitable position for artificial posterior teeth.

REFERENCES

- 1) Winkler S. Essentials of complete denture prosthodontics, WB Saunders Co., Philadelphia, USA, 1979, pp.301-388.
- 2) Koshino H, Hirai T, Ishijima T, Ohtomo K. Influence of mandibular residual ridge shape on masticatory efficiency in complete denture wearers. *Int J Prosthodont* 2002; 15:295-298.
- 3) Suenaga K, Sato T, Nishigawa G, Minagi S. Relationship between size of denture area and resorption of alveolar ridge in the edentulous mandible. *J Oral Rehabil* 1997; 24:315-319.
- 4) Sato Y, Tsuga K, Yoshida M, Kubo T. Factors influencing the clinical composite assessment of denture-supporting tissue. *Int J Prosthodont* 2002; 15:49-54.
- 5) Kawahata N, Kamashita Y, Nishi Y, *et al.* Analysis of residual ridge and ridge relationship by three-dimensional reconstruction method. *J Oral Rehabil* 1998; 25:110-116.
- 6) Kawahata N, Kamada Y, Ohtsuka A, *et al.* A visual method for analyzing buccolingual position of artificial posterior teeth. Part 1: Use of the ridge crest. *J Oral Rehabil* 1998; 25:914-920.
- 7) Hickey JC, Zarb GA. Boucher's prosthodontic treatment for edentulous patient, 8th ed, CV Moby, St. Louis, MO, 1980, pp.117-143,170-200, 339-357.
- 8) Heartwell C, Rahn A. Syllabus of complete dentures, 3rd ed, Lea & Febiger, Philadelphia, 1980, pp.311-326.
- 9) Watt DM, MacGregor AR. Designing complete dentures, 2nd ed, Wright, Bristol, 1986, pp.3-47, 89-118.
- 10) Murakami M, Ohtsuka A, Kajii M, *et al.* Shape analyzing system for mandibular edentulous distal-extension ridge Study on the examination method for the anteroposterior inclination. *J Jpn Prosthodont Soc* 1999; 43:821-829.
- 11) Gysi A. Special teeth for cross-bite cases. *The Dental Digest* 1927; 33:99-101.
- 12) Sanghvi SJ, Bhatt NA, Bhargava K. An evaluation of cross-bite ridge relationships. A study of articulated jaw records of 150 edentulous patients. *J Prosthet Dent* 1981; 45:24-29.
- 13) Kawano F, Nagao K, Inoue S, Matsumoto N. Influence of the buccolingual position of artificial posterior teeth on the pressure distribution on the supporting tissue under a complete denture. *J Oral Rehabil* 1996; 23:456-463.
- 14) Nishigawa G, Matsunaga T, Maruo Y, *et al.* Finite element analysis of the effect of the bucco-lingual position of artificial posterior teeth under occlusal force on the denture supporting bone of the edentulous patient. *J Oral Rehabil* 2003; 30:646-652.
- 15) Kapur KK, Soman S, Shapiro S. The effect of denture factors on masticatory performance. Part 3. The location of the food platform. *J Prosthet Dent* 1965; 15:451-463.

- 16) Sohmura T, Kojima T, Wakabayashi K, Takahashi J. Use of an ultrahigh-speed laser scanner for constructing three-dimensional shapes of dentition and occlusion. *J Prosthet Dent* 2000; 84:345-352.
- 17) Wakabayashi K, Sohmura T, Takahashi J, *et al.* Development of the computerized dental cast form analyzing system Three dimensional diagnosis of dental arch form and the investigation of measuring condition. *Dent Mater J* 1997; 16:180-190.
- 18) UNISN Inc. Operating manual of Surflacer VMS-250R. 3-4. UNISN, Osaka, 1992.
- 19) Takamata T, Hashimoto K, Boone ME, Goodacre CJ. The application of Moire topography to removable prosthodontics. *Int J Prosthodont* 1989; 2:65-72.
- 20) Beresin VE, Schiesser FJ. The neutral zone in complete dentures. *J Prosthet Dent* 1976; 36:356-367.
- 21) Fahmi FM. The position of the neutral zone in relation to the alveolar ridge. *J Prosthet Dent* 1992; 67:805-809.